DATA COLLECTION OPERATIONAL SUPPORT SYSTEM
PART II

Federation Engineering Staff

Federation of Rocky Mountain States, Inc
2480 W. 26 Ave. Suite 300B
Denver, Colorado 80211

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Final Report

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16. Abstract

This part of the final report details the calibration of 10 receiving sites in the Rockies.

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Calibrated signal-strength data has been obtained by Bill Lane at 10 HET sites in the Rockies. (Ref: Appendix B and C.) Average HP signal strength readings from these same 10 sites have been obtained from OMR cards in the period extending from November 7, 1974, to May 14, 1975. Additionally, NASA telemetry data regarding the signal levels in the ATS-6 spacecraft from transmissions originated by Rosman, Seattle, Omak, College, and Morrison was compiled by the NCC.

The purpose of this report is to present the data and develop a methodology to use this data to compute the carrier-to-noise ratios (CNR's) and signal-to-noise ratios (SNR's--in particular, peak-to-peak video to weighted rms noise ratios) at each of the calibrated sites and to estimate the median values of these quantities for sites in the Rockies, Alaska, and Appalachia.

The results pertaining to the calibrated sites are quite accurate (± 1.5 dB); the same cannot be said for the estimates concerning median sites in Alaska, Appalachia, and the Rockies.

Nine of the 10 calibrated sites (the exception being Panguitch, Utah), were far from beam center. Nonetheless, calculated CNR's range from 13.4 dB to 19.4 dB and the calculated SNR's range from 46.3 dB to 52.3 dB. The median SNR of 56 sites in the Rockies is estimated to be 51.1 dB; the median SNR for sites in Appalachia and Alaska is estimated to be 48.1 dB and 45.6 dB, respectively.

It is not clear why average ARC sites received significantly less signal than average Rocky Mountain sites. Either the geometry of the coverage pattern from ATS-6 placed a higher percentage of ARC sites at the periphery of the footprint, or the ARC operators were comparatively lax in pointing their receiving antenna correctly. The larger path loss from ATS-6 to Alaska, the low EIRP of the transmitters used for Alaska broadcasts (in Seattle, Omak, and College), and the extremely low elevation angles of the receivers in Alaska explains the lower signal levels received in this area.

The signal-to-noise ratio is related to the total received carrier-to-noise ratio by the FM equation:

$$SNR = (3/2)\ (\Delta F/f_m)^2\ (CNR)\ (B/f_m)\ k_w\ k_p\ k_c/k_i \qquad (1)$$

where:

ΔF = Peak frequency deviation = 8.25 MHz

f_m = Maximum video baseband frequency = 4.2 MHz

B = RF noise bandwidth = 24.675 MHz

k_w = Noise-weighting improvement factor = 10.2 dB

k_p = Preemphasis improvement = 2.4 dB

k_c = rms-to-peak-to-peak conversion factor for video = 6.0 dB

k_i = implementation loss = 1.0 dB

ΔF_{audio} = Peak frequency deviation of the main carrier by the audio subcarriers = 1.0 MHz

Jim Janky empirically evaluated the relationship between SNR and CNR in a memo to Dail Ogden dated February 4, 1975. (Ref: Appendix A.) The data of Table I of this memo suggests that an implementation loss of 1.0 dB is conservative for CNR's in the neighborhood of 16.5 dB and a ΔF of 8.25 MHz. Substituting the appropriate values into equation (1) results in the expression:

$$SNR = CNR + 32.9 \text{ dB} \tag{2}$$

The conventional practice is to relate the RF bandwidth, B, to the frequency deviation, ΔF, and maximum baseband frequency, f_m, using Carson's rule:

$$B = 2\,(\Delta F + f_m + \Delta F_{audio}) = 2\,(8.25 + 4.2 + 1.0) = 26.90 \text{ MHz}$$

The RF bandwidth used in the HET experiment, 24.675, represents a modest amount of "overdeviation."

The total carrier-to-noise in the satellite link is calculated as follows:

$$\frac{1}{CNR_T} = \frac{1}{CNR_{up}} + \frac{1}{CNR_{down}} + \frac{1}{CNR_{misc}} \tag{3}$$

CNR_{up} pertains to the path from the ground transmitters to ATS-6, CNR_{down} pertains to the path from ATS-6 to a HET receiver, and CNR_{misc} pertains to other miscellaneous noise sources. In a satellite television link, this miscellaneous contribution typically amounts to less than 12% of the total noise. For concreteness, assume that:

$$\frac{1}{CNR_{misc}} = (0.12)\left(\frac{1}{CNR_T}\right) \quad \text{or}$$

$$\frac{1}{CNR_T} = \frac{1}{0.88}\left[\frac{1}{CNR_{up}} + \frac{1}{CNR_{down}}\right] \tag{4}$$

Telemetry data from ATSOCC over the period January 7, 1975, to May 15, 1975, indicates that the average signal level from Morrison into the C-band transponder on ATS-6 (using the earth coverage horn antenna at 5947.5 MHz) was -70.41 dBm. The system noise figure for this transponder is estimated by NASA to be 7.13 dB,* which corresponds to a system noise temperature of:

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* Goddard Space Flight Center, The ATS-F Data Book, Greenbelt, Maryland, pg. II-70, May, 1974.

$$
\begin{aligned}
T &= (F-1)\ T_o \\
&= (5.164 - 1)\ (290°K) \\
&= 1208°\ K \qquad (5)
\end{aligned}
$$

The average uplink carrier to noise ratio was approximately:

$$
\begin{aligned}
CNR_{up} &= C_{in} - k - B - T \\
&= -70.41 + 198.6 - 73.92 - 30.82 \\
&= 23.45 \text{ dB} \qquad (6)
\end{aligned}
$$

The downlink CNR is inferred from calibration data obtained by Bill Lane. That is, the relationship between the input signal level at the HET terminal and its indoor meter reading was established empirically. The following assumptions are made:

1. The characteristics of the equipment did not change over time;

2. The HP readings were taken after the equipment had warmed up. (Site operators were instructed never to turn off the equipment); and

3. The calibration data is accurate. (The signal sources and attenuators were calibated in July, 1975 by Martin Marietta before Lane obtained the data at the sites.)

Lane returned from the field with the preamplifiers, the noise temperatures of which were then measured in the laboratory. Jim Potter has analyzed this data and tabulated the results in Table I of this report.

The results are incredibly good. Are they real? Jim Janky measured the SNR of the S-band receiver at Morrison, which was on the periphery of the southeast footprint. The measured result was 49.7 dB. This result can be calculated as follows:

Path loss (2569 MHz)	=	192.74 dB
EIRP (ATS-6 - peak)	=	82.7 dBm
Antenna Gain (54% efficiency)	=	35.62 dB
Off-axis loss	≃	4.5 dB

$$C_{in} \simeq 82.7 - 192.74 - 4.5 + 35.62 = -78.9 \text{ dBm}$$

The noise figure of the S-band receiver at Morrison is approximately 4.2 dB, or the system noise temperature is approximately 548°K. The downlink carrier-to-noise ratio, then, is approximately

$$CNR_{down} = -78.9 + 198.6 - 73.92 - 27.4 = 18.3 \text{ dB}$$

For an uplink CNR of 23.45 dB and 12% miscellaneous noise, the total CNR is approximately 16.6 dB, leading to an SNR of approximately 49.5 dB, 0.2 dB lower than the measured result. Thus, there is extremely close agreement.

In conclusion, the performance of the HET terminals was excellent, with SNR's in the Rockies typically ranging from 46.3 to 52.3 dB with a median level of 51.1 dB. The conservative assumptions which were used to design the HET terminals resulted in performance levels that significantly exceeded expectations.

SNR's and CNR's
(11/7/74 - 5/15/75)

Site	HP SS	C_{in} (dBm)	Noise Figure	Sys. Noise Temp.*	CNR down	CNR_T (dB)	SNR (dB)
Hayden, AZ	13.11	-82.86	4.20 dB	548°K	14.43 dB	13.4	46.3
Gila Bend, AZ	17.02	-75.98	4.34 dB	573°K	21.11 dB	18.6	51.5
St. Johns, AZ	16.90	-76.20	4.27 dB	560°K	21.00 dB	18.5	51.4
W. Yellowstone, MT	18.45	-77.03	4.07 dB	525°K	20.44 dB	18.1	51.0
Whitehall, MT	16.78	-77.72	4.20 dB	548°K	19.57 dB	17.5	50.4
Heber City, UT	15.70	-82.43	4.38 dB	580°K	14.61 dB	13.5	46.4
Panguitch, UT	19.02	-74.96	4.00 dB	513°K	22.62 dB	19.4	52.3
Pinedale, WY	16.11	-77.78	4.20 dB	548°K	19.51 dB	17.5	50.4
Saratoga, WY	17.87	-77.13	4.20 dB	548°K	20.16 dB	17.9	50.8
Sundance, WY	18.45	-76.55	4.05 dB	522°K	20.95 dB	18.4	51.3
Median Rockies (56 sites)	17.20	-76.72**	4.20 dB**	548°K	20.57 dB	18.2	51.1
Median ARC***	14.76	-81.12**	4.20 dB**	548°K	16.17 dB	15.2	48.1
Median Alaska****	14.40	-81.73**	4.20 dB**	548°K	15.56 dB	12.7	45.6

* The receiver noise temperature is calculated from the expression $T_n = (F-1)(290)$. It is assumed that the net contribution from sky noise and insertion loss is 75°K. The system noise temperature, then, is related to the receiver noise figure in the following manner: $T_{sys} = (F-1)(290°) + 75°K$, where F is the antilog of the receiver noise figure in decibels.

** Estimated.

*** The ARC typically received their programming from Rosman, which provided a higher EIRP than Morrison. The average uplink CNR in the period between November 1, 1974, and May 14, 1975, is estimated from telemetry data to be 26.82 dB. Noise contributed from the microwave link between Lexington, Kentucky, and Rosman, North Carolina, is assumed to be negligible. Note that the estimated median received signal strength in the ARC (-81.12 dBm) is 4.4 dB lower than the estimated median received signal strength in the Rockies.

**** Alaska typically received their programming from Seattle, Omak, or College. The average uplink CNR from January 7, 1975, to May 14, 1975, is estimated to be 17.18 dB. It is assumed that noise contributed by the signal sources (cameras or VTR's), the microwave link, and nonlinearities in the electronics of the transmitting station are negligible.

APPENDIX A

M E M O R A N D U M

FEDERATION OF ROCKY MOUNTAIN STATES

Satellite Technology Demonstration

TO: Dail Ogden

FROM: Jim Janky

SUBJECT: Deviation and Signal to Noise Ratio Measurements Over ATS-6 at Morrison Earth Station

DATE: February 4, 1975

Several link performance measurements were made at the Morrison Earth Station on January 9, 1975, involving video signal-to-noise ratio and video distortion (objective and subjective measures) as a function of carrier deviation and carrier-to-noise ratio. The important results of this brief measurement are as follows:

1. The peak-to-peak video to weighted rms noise ratio on that day was 49.7 dB, with an HP meter reading of 14.75. This is about 2 dB less than was predicted in 1972; however, the peak deviation of the carrier is now set to 8.25 MHz instead of the original 10 MHz level, and this accounts for 1.67 dB of the difference. We are therefore achieving the performance levels we expected, to within measurement accuracy (±1 dB).

2. Signal-to-noise ratio measurements were made over the ATS-6 link for deviations from 5 MHz to 9.25 MHz, using the test setup shown in Figure 1A. The carrier-to noise measurements were made by Dr. Potter and our own observations (see Appendix IA for calculations). The results are summarized in Table 1A. In every case, the measured SNR was less than the calculated value. The average discrepancy is 0.81 dB. Based on the possible uncertainty in carrier-to-noise ratio calculations of ±.5 dB, it seems prudent to continue to subtract something for implementation loss and measurement errors. A minimum estimate in my opinion would be 1.3 dB, maximum would be 1.8 dB, and a mean would be 1.5 dB.

3. The peak deviation of the carrier was reduced to its present 8.25 MHz level to eliminate the threshold noise spikes (black dots) which occur at moderate carrier-to-noise ratios when the rf bandwidth of the signal begins to exceed the 3 dB bandwidth of the filter in the receivers. We are overdeviating even now at 8.25 MHz, if we define 3 dB bandwidth by Carson's rule

$$\text{RF BW}_{3\text{ dB}} = 2(\Delta F_{video} + F_{max}) + 2\sqrt{N}\,\Delta F_{audio}$$

The first term is due to the video and the second term is due to the audio subcarriers. In our case, N = 4, and the extra bandwidth required for the audio subcarriers is approximately 2 MHz. The rf bandwidths for various deviations are

listed in Table IIA. The onset of video distortion occurs with our receiver system at a deviation of 9.25 MHz. This distortion is primarily characterized by the rapid increase in black dots on the screen. As can be seen in the Table, the Carson's rule bandwidth at the onset of distortion is 28.9 MHz. Our 3 dB bandwidth in the HP receiver is 23.5 MHz. And even at a deviation of 8.25 MHz, the Carson's rule bandwidth is 26.9 MHz. We are therefore, overdeviating, but not to the extent first thought feasible. It appears that at most a 10% increase in deviation is possible as compared to what is calculated by Carson's rule. This estimate applies <u>only</u> in the region of our particular carrier-to-noise ratio, 16 dB. For higher carrier-to-noise ratios, greater overdeviations are possible. In a test conducted at the DUT earlier, with a CNR greater than 50 dB, the onset of distortion did not occur until a deviation of 16 MHz was reached. However, at lower CNR's (10-13 dB), no degradation at 8.25 MHz deviation was observed.

4. Measurements were made on our spectrum analyzer of the bandwidths of a color-bar modulated FM signal for various deviations. The bandwidths noted in Table IIIA are for 99% energy content (-40 dB sideband levels), 95% (-26 dB), and 90% (-20 dB).

TABLE IA. Signal-to-Noise Ratio Measurements as a Function of Deviation ΔF

ΔF, MHz	β	FMI, dB	CNR & Emphasis	Calculated TT-SNR	Measured TT-SNR	Difference	Measured Total SNR, dB
5.0	1.1915	10.97	18.98	29.95	28.0	- 1.95	44.2
8.0	1.915	15.04	18.98	34.02	34.0	- 0.02	50.2
8.25	1.960	15.31	18.98	34.28	33.5	- 0.79	49.7
9.25	2.20	16.31	18.98	35.29	34.8	- 0.49	51.0
10.00	2.381	16.98	18.98	35.96	--	--	--

Calculated Testtone (TT) SNR = CNR • FMI • Emphasis

Total SNR = TT-SNR • Peak-to-peak • Weighting

FMI = FM Improvement Factor

$$= 3/2\,\beta^2 \frac{BW_{rf}}{BW_{bb}} = \frac{3}{2} \cdot \frac{(1.05)(23.5)}{4.2}\beta^2 = 8.8125\,\beta^2$$

Maximum Modulating Frequency = 4.2 MHz
Emphasis = 2.4 dB (CCIR Standard)
CNR = 16.58 dB (Calculated; See Appendix IA)
Peak-Peak Factor = 6 dB ($\approx$10 log 8)
Weighting Factor = 10.2 dB (CCIR Standard)

TABLE IIA. Carson's Rule Bandwidths for Specific Deviations, MHz

ΔF_v	$2(\Delta F_v + F_{max})$	$2\sqrt{N}\ \Delta F_{audio}$**	Total BW
5	18.4	2	20.4
8	24.4	2	26.4
8.25	24.9	2	26.9
9.25	26.9	2	28.9*
10.00	28.4	2	30.4

*Onset of distortion with 16.5 dB CNR and 23.5 MHz 3 dB RF Bandwidth
**Audio deviation = $2\sqrt{4} \cdot 0.5 = 2$ MHz rms.

TABLE IIIA. Bandwidth Measurements

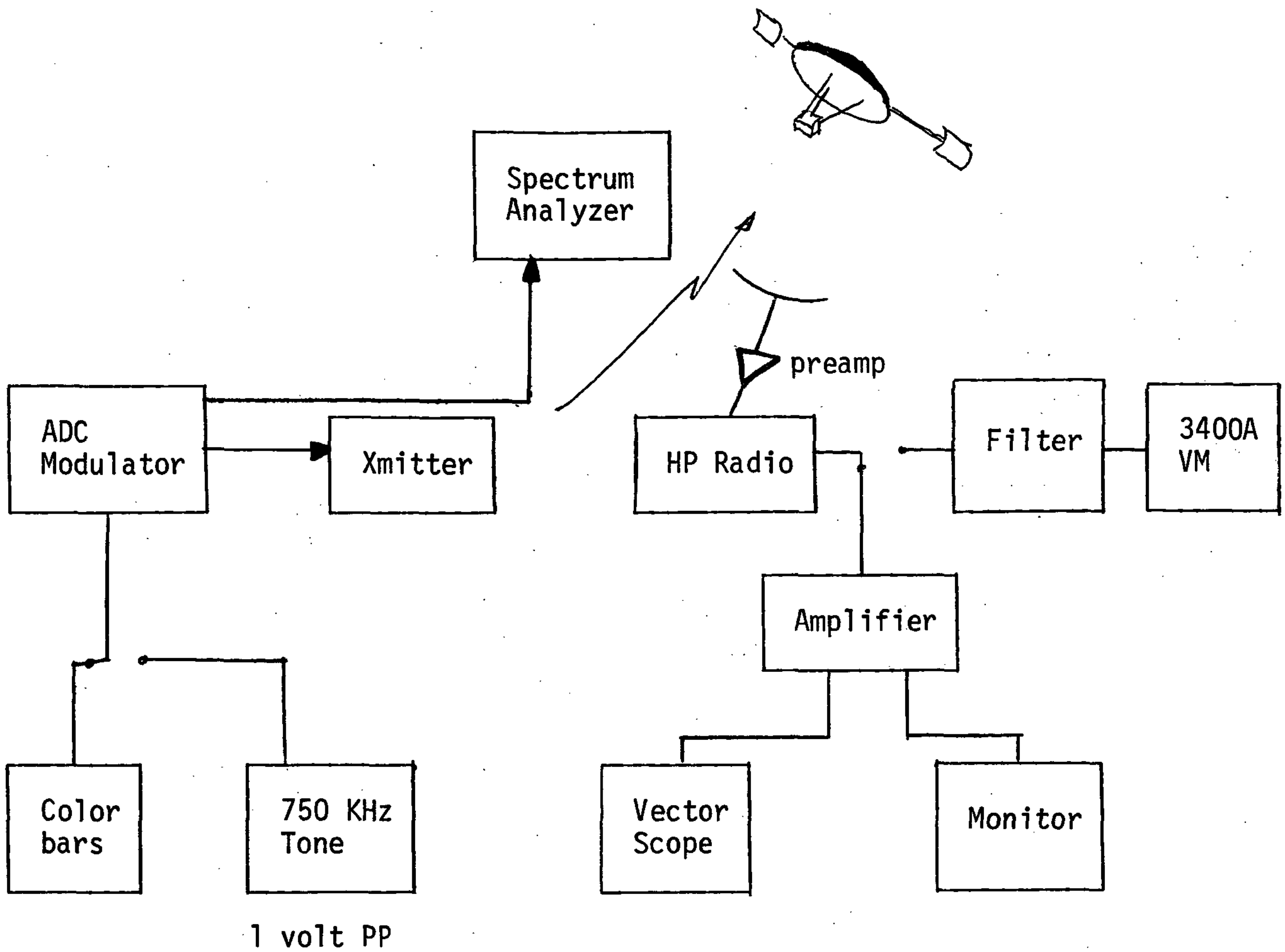
Various bandwidths for a color bar video signal are listed below as a function of percent energy included in the given bandwidth, for various deviations.

% Energy Included	Sideband Level	Deviation ΔF, MHz 5	8.25	9.25	15
99%	-40 dB	29	37	44	60
95%	-26 dB	25	30	36	46
90%	-20 dB	16	26	30	40

APPENDIX IA. Carrier-to-Noise Calculation

$$CNR = \frac{\text{Signal level}}{k \cdot T_s \cdot BW}$$

Signal level corresponding to "14.75" on HP meter		- 81 dBm
		-111 dBW
k		-228.60 dB/°K - Hz
BW	Noise Bandwidth 24.675 MHz	73.92 dB - Hz
Sky Temperature and Misc. Losses:	75°K	
T_s System Noise Temperature		
	Low estimate: 3.8 dB NF = 405°K + 75°K	26.81 dB - °K
	Mean estimate: 4.0 dB NF = 438°K + 75°K	27.10
	High estimate: 4.2 dB NF = 472°K + 75	27.38
High estimate CNR		16.87 dB
Mean estimate CNR		16.58 dB
Low estimate CNR		16.30 dB



1. Set deviation with 1 V pp 750 KHz tone
2. Measure SNR
3. Examine vectorscope display, monitor display

FIGURE 1A

APPENDIX B

HP RECEIVER METER READINGS VS INPUT SIGNAL LEVEL

Site: Input (dBM):	Hayden	Gila Bend	St. Johns	West Yellowstone	Whitehall
-70	23.0	23.5	21.0	28.5	29.0
-71	21.8	22.0	20.5	24.8	26.0
-72	20.3	20.5	19.8	23.0	21.0
-73	19.7	19.9	19.0	22.0	20.0
-74	18.8	19.0	18.5	20.5	19.5
-75	17.7	18.0	17.5	19.8	18.5
-76	16.8	17.0	17.0	19.2	18.0
-77	16.1	16.5	16.5	18.5	17.5
-78	15.7	16.0	16.0	17.0	16.5
-79	15.2	15.5	15.1	16.5	16.0
-80	14.8	14.9	14.5	15.8	15.4
-81	14.4	14.5	14.0	15.0	15.0
-82	13.8	14.0	13.5	14.7	14.5
-83	13.0	13.0	13.0	14.0	14.0
-84	11.9	12.0	11.5	13.0	13.0
-85	10.9	11.0	10.5	12.0	12.5
-86	10.3	10.5	10.0	10.3	12.0
-87	9.7	9.9	9.0	9.9	11.0
-88	8.8	9.0	8.5	9.5	10.0
-89	7.8	8.0	7.5	9.2	9.5
-90	6.9	7.0	6.5	8.1	8.2

APPENDIX B

HP RECEIVER METER READINGS VS INPUT SIGNAL LEVEL

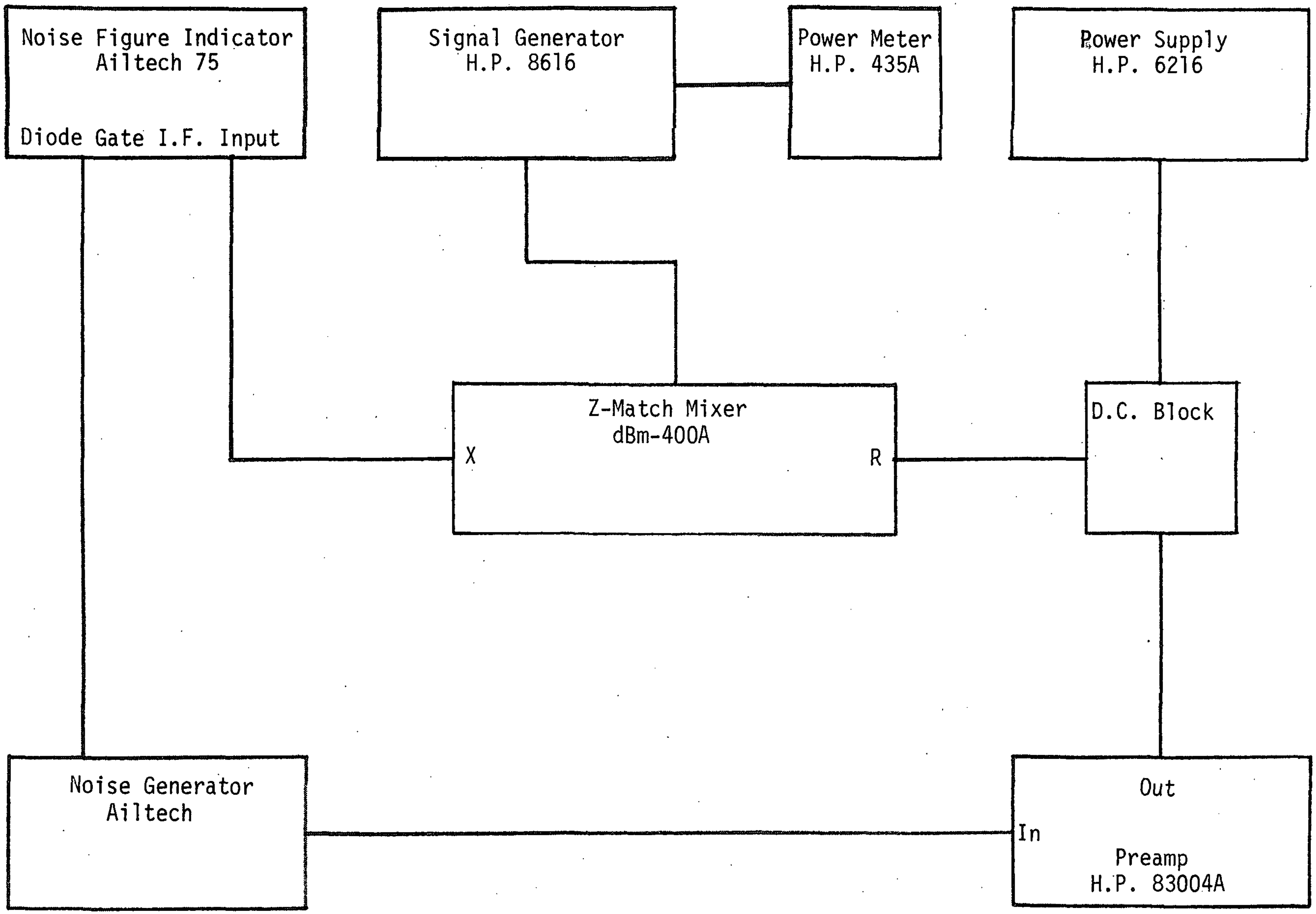
Site: Input (dBM):	Heber City	Panguitch	Pinedale	Saratoga	Sundance
-70	30.0	24.0	28.5	28.5	28.2
-71	26.0	23.0	24.5	26.0	25.6
-72	24.6	22.0	22.0	23.0	23.9
-73	23.0	20.5	20.0	21.5	21.3
-74	22.0	19.5	19.5	20.5	20.2
-75	21.0	19.0	18.8	19.5	19.5
-76	20.4	18.0	17.5	19.0	19.0
-77	19.9	17.0	16.5	18.0	18.0
-78	19.0	16.5	16.0	17.0	17.0
-79	18.5	16.0	15.5	16.5	16.2
-80	17.5	15.1	15.0	16.0	15.5
-81	16.9	14.5	14.5	15.0	15.1
-82	16.0	14.0	13.8	14.8	14.5
-83	15.3	13.5	13.0	14.0	13.6
-84	14.9	12.5	12.0	13.5	12.5
-85	14.0	11.0	11.0	12.5	12.0
-86	13.2	10.2	10.1	11.5	11.0
-87	12.0	9.8	9.9	10.2	10.1
-88	11.0	9.0	9.0	9.8	9.3
-89	10.3	8.0	8.0	9.0	8.3
-90	9.0	7.0	7.0	8.0	7.2

APPENDIX C

NOISE FIGURE TESTS

Serial No.		2560 GHz	2670 GHz
1332A00155	W. Yellowstone	4.33	4.07
1332A00211	Pangüitch	4.0	3.85
1332A00132	Sundance	4.13	4.05
1332A00123	Heber City	4.39	4.15
1332A00146	Gila Bend	4.34	4.15
1332A00166	St. Johns	4.27	4.07
1332A00138	Saratoga	4.32	4.08
1332A00210	Whitehall	D E F E C T I V E	
1332A00130	Pinedale	4.38	4.07
	Hayden	NOT AVAILABLE FOR TESTING	

See attached sheet for test setup.



Noise Figure Indicator
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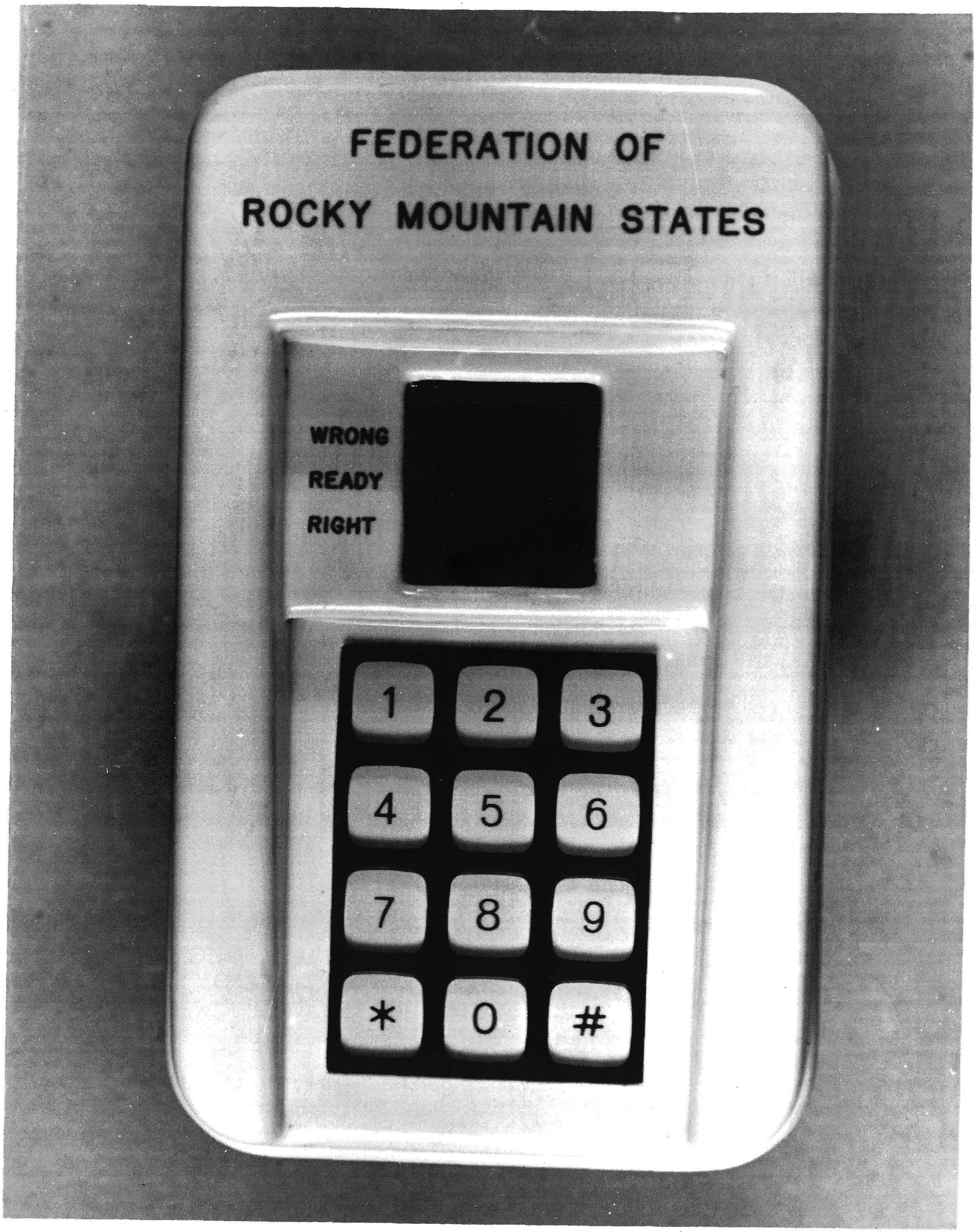
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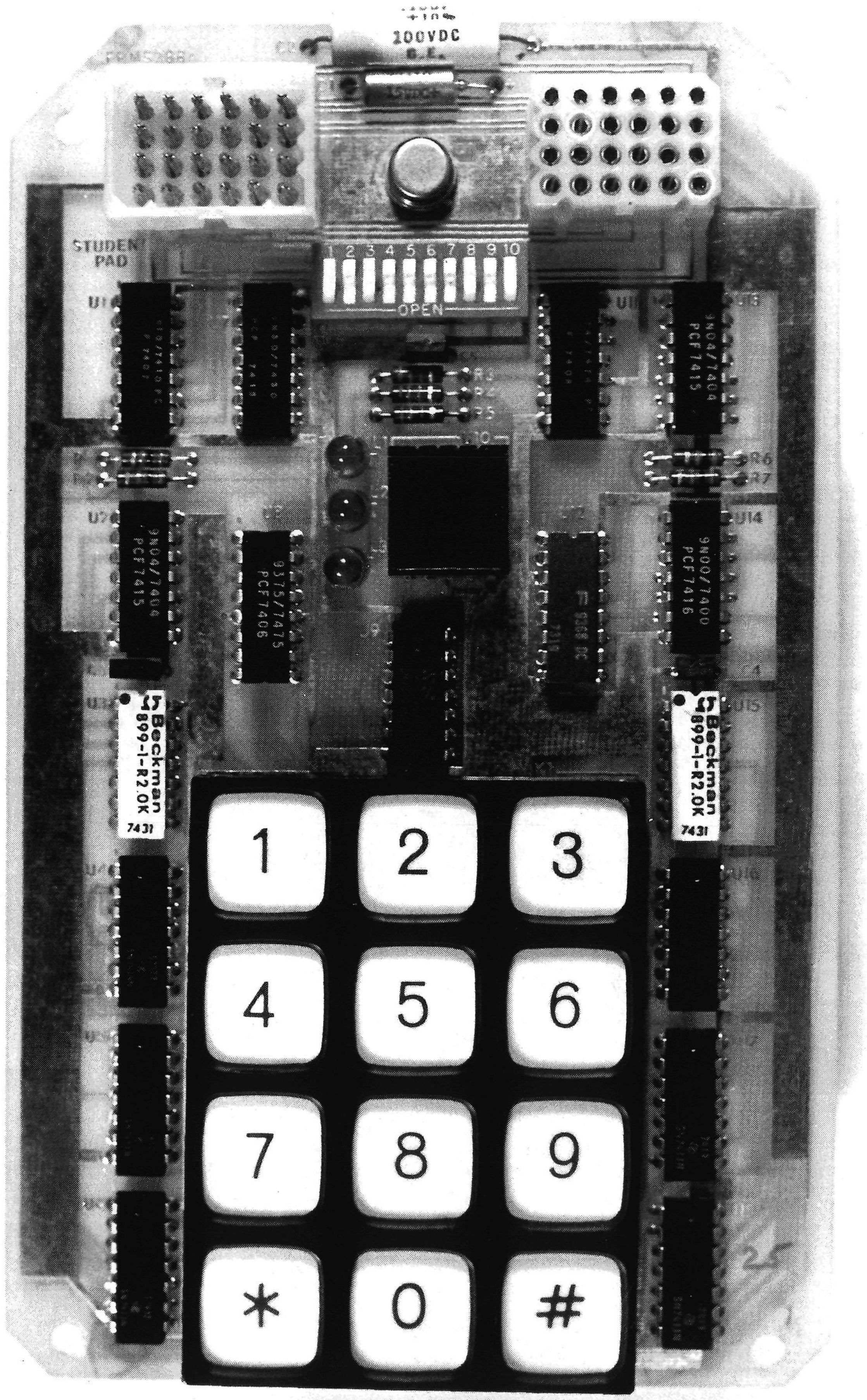
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